ASSESSING THE ECONOMIC VALUE OF UNDERGROUND HYDROGEN STORAGE FOR GERMANY'S ENERGY SUPPLY SECURITY

Ange BLANCHARD[1,2] | +33 7 88 37 75 38 | ange.blanchard@chaireeconomieduclimat.org

Camille MEGY[1,3,4] | +33 6 67 65 02 77 | camille.megy@centralesupelec.fr

Olivier MASSOL[1,2,3,4,5] |+33 6 64 38 16 46 | olivier.massol@ifpen.fr

Sébastien LEPAUL[1] | +33 6 62 3743 22 | sebastien.lepaul@edf.fr

1 Université Paris-Saclay, CentraleSupélec, Industrial Engineering Research Department, France
2 Chaire Economie du Climat, Université Paris Dauphine, France
3 IFP Energies Nouvelles, France
4 IFP School, France
5 City, University of London, Department of Economics, UK

Overview

The adoption of hydrogen technology is a crucial solution for reducing carbon emissions in hard-to-decarbonize sectors [1]. Germany is currently the largest consumer of hydrogen in Europe and its demand is expected to double by 2035. To meet this goal, the country intends to invest in electrolysis capacity and to heavily rely on hydrogen imports, which should account for more than 75% of its supply [2]. To this end, Underground Hydrogen Storage (UHS) is considered an important tool for reducing the cost of hydrogen production and improving the reliability of the hydrogen supply chain [3].

This study examines the value of salt caverns in providing long-term hydrogen storage in Germany by 2035 by evaluating the economic value of it, streaming both from the unleashed opportunity of time arbitrage it provides and its hedging value against potential supply disruptions from international partners.

To appropriately account for the uncertainty on renewable energy sources generation, we use an innovative approach by implementing a Stochastic Dual Dynamic Programming (SDDP) algorithm, along with a Markov Chain representation of the supply disruption hazard.

Our research indicates that UHS facilities can help reduce the need for costly hydrogen supply capacity infrastructures and serve as a hedge against supply risks. The study concludes that the decision to invest in a UHS project is substantially affected by its hedging role, and that this dimension should be carried by a political support, through subsidies or capacities tenders.

Methods

The model presented in this paper is an hourly investment and dispatch model of the 2035 German power and hydrogen system. It includes power and hydrogen production assets as well as power and hydrogen storage facilities. However, it overlooks spatial considerations and the role of energy transportation infrastructures.

We consider a one-year time horizon to account for seasonal variations in energy demand and supply. Our modelling framework focuses on the operations of assets with exogenously predetermined capacities, except for UHS facilities, which optimal level of investment is determined endogenously.

From a modelling perspective, previous studies on UHS typically involve the solution to a deterministic cost-minimization problem [4,5]. However, such models may not accurately account for the effects of the unpredictability of variable renewable generation sources on the system performance. To address this drawback, this analysis is conducted using an innovative approach that consists in setting up a stochastic representation of the power and hydrogen system based on the so-called SDDP framework [6]. This complex modeling approach was first developed in Brazil to model the local hydro-dominated power system and is now increasingly popular to model and evaluate the value of the storage operations performed in an energy system (e.g., [7] [8]). However, to the best of our knowledge, the SDDP technique has so far never been applied to model the provision of flexibility and insurance services provided by underground hydrogen storage.

Another major contribution of this work is to assess the value of stored hydrogen when considering the potentiality of a supply disruption. The way the latter has been implemented is through the use of a Markov Chain, introducing a random variable to characterize whether the system undergoes a cut in imported hydrogen or not.

Results

First, an assessment of the value of UHS for time arbitrage and hedging is carried out by comparing a case without UHS to a case where investments in UHS are permitted. We show that UHS fills its role of time arbitrager in the hydrogen system by dampening the production variation through time, which yields lower hydrogen imports peaks, and smoother patterns for every technology. However, the introduction of UHS does not reduce the amount of curtailed electricity, the conversion of electricity into hydrogen being limited by the electrolyzer capacity. Thus, the lack of electrolyzer capacity limits the ability of hydrogen storage to provide flexibility to the electrical system.

Second, we seek to assess the premium value of UHS when considering a supply disruption. We compare three cases with allowed UHS investment and different probability of hydrogen imports disruption. We show that when the supply disruption risk is null, the optimal investment level is relatively low, reflecting the purely time-arbitrage value of UHS assets. In a high-risk scenario, the optimal investment level increases by more than 50%. Most of the UHS capacity is then installed to hedge against the risk of disruption. Moreover, we show that the opportunity cost of stored hydrogen increases with the estimated probability of supply disruption. The value given to the hedging capacity of UHS can thus be extracted from our simulations by comparing the opportunity costs of stored hydrogen in a case without supply disruption to a case with an estimated probability of supply disruption.

Conclusions

Hydrogen technology has been identified as a vital solution for reducing carbon emissions in sectors that are difficult to decarbonize. To achieve this goal and meet its climate objectives, Germany intends to invest in electrolysis and rely on hydrogen imports, which has led to the exploration of Underground Hydrogen Storage (UHS) as a tool to reduce hydrogen production costs and improve energy system reliability.

This study sheds light on the economic value of UHS facilities in Germany for the coming decade. Since the construction time of such sites are of about 8 to 10 years, it is critical to know whether these are expected to be relevant or not in the future, to inform current investment decisions.

Using a dynamic stochastic optimization algorithm based on the SDDP framework and a Markov Chain, the research indicates that UHS facilities not only allow for time arbitrage and hedging from green hydrogen production variation, but also help to reduce the need for expensive hydrogen imports and serve as a hedge against supply risks. We show that UHS facilities provide better performance in times of supply disruption by serving as a backup supply of hydrogen, and we propose a method to quantify a premium accounting for this strategic value. We believe that this modeling framework provides valuable insights to assess the value of hydrogen to be taken for investments in UHS or electrolysers facilities.

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